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TESTS OF SMALL-SCALE EXPLOSIONS IN EXTREMELY SHALLOW WATER

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

October 1954

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CORPS OF ENGINEERS, U. S. ARMY

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MISCELLANEOUS PAPER NO. 2-103

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WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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Preface

In preparation for Operation Castle, the U. S. Naval Ordnance Laboratory requested the Waterways Experiment Station to determine by means of TNT charges the magnitudes of water shock and air blast resulting from explosions in extremely shallow water. Actual authority for the Experiment Station to conduct the investigation was contained in a letter, dated 29 July 1953, from the Office, Chief of Engineers.

The investigation was conducted during November and December 1953 by the Hydraulics Division of the Waterways Experiment Station, under the general supervision of Mr. F. R. Brown. Mr. G. L. Arbuthnot, Jr., Chief of the Special Investigations Section, was in direct charge of the tests and was assisted by Messrs. J. N. Strange and F. A. Pieper.

Contents

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Summary

Six 100-lb spherical charges of cast TNT were fired in a water depth of 0.41 ft over both a sand and concrete bottom. Pressure-time measurements were obtained at distances of 22, 30, and 50 charge radii from the charge by means of tourmaline, piezoelectric gages located above and below the water surface. Test results indicated that water shock in extremely shallow water is negligible compared to the air blast at distances equal to or greater than 22 charge radii.

TESTS OF SMALL-SCALE EXPLOSIONS IN EXTREMELY SHALLOW WATER

Introduction

1. The tests of small-scale explosions in extremely shallow water, conducted for the Naval Ordnance Laboratory, were concerned with measurements of air- and water-shock pressures produced by the detonation of 100-lb spheres of cast TNT in a water depth of 0.41 ft, over both a sand and a concrete bottom.

2. The tests were conducted at the Waterways Experiment Station explosives test site located on Big Black River about 10 miles east of Vicksburg, Mississippi. A sand bed 40 ft long, 20 ft wide, and about 6 ft deep was provided for the tests over the sand bottom (shots 1-3). The sand bed was located in the central portion of a previously excavated test basin which was 100 ft square and about 7 ft deep. Tests over the concrete bottom (shots 4-6) were fired over a massive concrete slab 12 ft wide, 40 ft long, and 6 ft thick. This slab was located in a second test basin that was similar in size to the one described above. Both test basins as well as the concrete slab and sand bed had been utilized previously in another testing program.*

Test Conditions

3. The test conditions are summarized on the following page. In each shot the charge (W) was 100 lb of TNT (spherically shaped) and the actual water depth (D) was 0.41 ft ($D/W^{1/3} = 0.088$).

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* Report of Waterways Experiment Station study of the effects of explosions on gravity dams, unpublished.

Shot No.	Charge Position*	Type Bottom Material	Gage Positions** Horizontal Range in Charge Radii	Vertical Gage Position, ft +0.1	-0.1	-0.2	-0.3	-0.51***
1	Surface	Sand	30		x	x	x	
			50	x	x	x	x	x
2	Surface	Sand	30		x	x	x	
			50	x	x	x	x	x
3	Surface	Sand	22	x	x	x	x	x
			30	x		x		x
4	Bottom	Concrete	22	x	x	x	x	
			30	x	x	x	x	
5	Surface	Concrete	22	x	x	x	x	
			30	x	x	x	x	
6	Surface	Concrete	22	x	x	x	x	
			30	x	x	x	x	

* Charge position referenced to charge center of gravity.

** Vertical gage positions are referenced to the water surface, plus sign indicating above surface and minus sign below surface. Horizontal gage ranges are referenced to surface zero.

*** Gage buried 0.1 ft in sand.

For charges detonated over concrete (shots 4, 5, and 6), depressions were molded in the concrete bottom to permit accurate positioning of the charge. All charges were centrally initiated. Gages were placed in pairs at the locations shown. Test geometries for those shots that produced readable shock records are shown on plate 1.

4. The air- and water-shock pressures were measured with tourmaline, piezoelectric gages and were recorded on 10-in. strips of 35-mm film by rotating-drum cameras mounted on Dumont, Type 304H, cathode-ray oscilloscopes.

Test Results

5. Data obtained during the course of the study are presented in table 1. Good records were obtained from shots 3, 4, and 6; however, no water-shock pressures were recorded, except for shot 4. Based on such criteria as time of arrival, duration, and impulse, it appeared that the phenomenon recorded on shot 4 was actually water shock. Records

from shots 3 and 6 indicated air-blast data only. No readable records of water shock were obtained for shots 1 and 2 as the gain on the oscilloscopes was set too low in anticipation of measuring higher pressure values than were actually present. Records from shot 5 were obtained but could not be used because of the failure of the numbering mechanism that identifies each record with the corresponding gage locations. The impulse, duration, and shock velocity from shot 4 indicate that some water shock was present, although the energy of the shock wave was much less than the air blast occurring at the same range. For example, the water-shock peak pressure at 22 charge radii ($\lambda = 2.97$) was essentially the same as the air-blast pressure, whereas the water-shock duration and the resulting impulse were much less than the air-blast duration and impulse at the same range.

6. On plate 2 the test data, shown as the plotted points, are compared with air-blast and water-shock measurements obtained from two previous WES studies.* The solid lines on plate 2 show results of water-shock measurements in scaled water depths of 400, 200, and 100 ft. In each case the charge and gages were positioned at mid-depth. The dashed lines show the results of air-blast measurements for charges positioned at the water surface (regardless of water depth) and with gages placed 1 ft above the water surface. The peak-pressure plot implies that while the gages were positioned below water surface, the resulting pressures were of the same order of magnitude as those recorded by the air-blast gages. The reduced positive impulse plot (plate 2) indicates that all gages recorded air blast except the below-surface gages (22 charge radii) of shot 4. Since the charge was positioned with its center of gravity at the bottom for shot 4, it is believed that more of the total energy released went into the water layer as water shock and the increased energy input was sufficient to be recorded as such by the gages; however, the attenuation of the shock

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* "Effects of Explosions in Shallow Water," Reports Nos. 5 and 6, January 1953 and April 1953, respectively, and report of WES study of the effects of explosions on gravity dams, unpublished.

front was such that no readable pressure pulse was recorded by the underwater gages at 30 charge radii ($\lambda = 4.05$).

Conclusions

7. From the results of tests reported herein, it is apparent that no appreciable water shock was in evidence at the reduced distances where measurements were attempted (22, 30, and 50 charge radii). Evidently the portion of the total energy released that was transmitted as a water-shock wave was rapidly attenuated by the interaction of reflections and rarefactions off the bottom and water surface.

Table 1

AIR- AND WATER-SHOCK MEASUREMENTS

100-lb Charges, $D/W^{1/3}$ = 0.088

Gage Position* (ft)	Peak Pressure (psi)	Positive Impulse (lb-sec/in.^{2})	Reduced Positive Impulse (lb-sec/in.^{2}/lb$^{1/3}$)	Positive Duration (sec)	Reduced Positive Duration (sec/lb$^{1/3}$)	Time of Arrival (sec)	Shock Velocity (ft/sec)
SHOT NO. 3, CHARGE AT SURFACE, BOTTOM MATERIAL - SAND							
Horizontal Distance, Charge to Gage, r_o = 22 (λ = 2.97)							
+0.10	40	0.026	0.0056	0.00208	0.00045	0.00304	4500
	79	0.048	0.0103	0.00212	0.00046	0.00304	4500
-0.10	31	0.016	0.0034	0.00070	0.00015	0.00298	4600
	75	0.064	0.0138	0.00178	0.00038	0.00293	4700
-0.20	34	0.033	0.0071	0.00190	0.00041	0.00300	4600
	64	0.078	0.0168	0.00236	0.00051	0.00296	4700
-0.30	29	0.031	0.0067	0.00142	0.00030	0.00292	4700
-0.51	27	0.022	0.0047	0.00118	0.00025	0.00304	4500
	45	0.067	0.0144	0.00202	0.00044	0.00304	4500
Horizontal Distance, Charge to Gage, r_o = 30 (λ = 4.05)							
+0.10	18	0.022	0.0047	0.00236	0.00051	0.00526	3600
	30	0.043	0.0093	0.00240	0.00052	0.00518	3600
-0.20	16	0.012	0.0026	0.00110	0.00024	0.00507	3700
SHOT NO. 4, CHARGE AT BOTTOM, BOTTOM MATERIAL - CONCRETE							
Horizontal Distance, Charge to Gage, r_o = 22 (λ = 2.97)							
+0.10	23	0.018	0.0039	0.00228	0.00049	0.00544	2500
	32	0.024	0.0052	0.00198	0.00043	0.00556	2500
-0.10**	65	0.00032	0.000069	0.000016	0.0000034	0.00251	5500
-0.20**	100	0.00019	0.000041	0.000010	0.0000022	0.00251	5500
	72	0.00047	0.000101	0.000016	0.0000034	0.00254	5400
-0.30**	67	0.00027	0.000058	0.000014	0.0000030	0.00248	5600
Horizontal Distance, Charge to gage, r_o = 30 (λ = 4.05)							
+0.10	22	0.034	0.0073	0.00312	0.00067	0.00830	2300
	19	0.017	0.0037	0.00185	0.00040	0.00835	2200
SHOT NO. 6, CHARGE AT SURFACE, BOTTOM MATERIAL - CONCRETE							
Horizontal Distance, Charge to Gage, r_o = 22 (λ = 2.97)							
+0.10	93	0.049	0.0106	0.00158	0.00034	0.00293	4700
	70	0.031	0.0067	0.00139	0.00030	0.00302	4600
-0.10	67	0.044	0.0095	0.00122	0.00026	0.00284	4300
	50	0.068	0.0146	0.00257	0.00055	0.00266	5200
-0.20	67	0.068	0.0146	0.00204	0.00044	0.00278	4900
	27	0.037	0.0080	0.00143	0.00031	0.00271	5100
-0.30	62	0.059	0.0127	0.00166	0.00036	0.00277	5000
	44	0.073	0.0157	0.00207	0.00045	0.00269	5100
Horizontal Distance, Charge to Gage, r_o = 30 (λ = 4.05)							
+0.10	60	0.051	0.0110	0.00258	0.00056	0.00464	4000
	38	0.008	0.0017	0.00046	0.00010	0.00472	4000
-0.10	40	0.058	0.0125	0.00266	0.00057	0.00451	4200
	36	0.048	0.0103	0.00267	0.00058	0.00444	4200
-0.20	23	0.023	0.0050	0.00116	0.00025	0.00452	4200
-0.30	29	0.028	0.0060	0.00140	0.00030	0.00460	4100
	38	0.030	0.0065	0.00150	0.00032	0.00446	4200

* All gage positions are referenced to the water surface, the minus signs denoting gages below surface and positive signs gages above surface.

** Records indicate that water-shock measurements were obtained at these gage positions.

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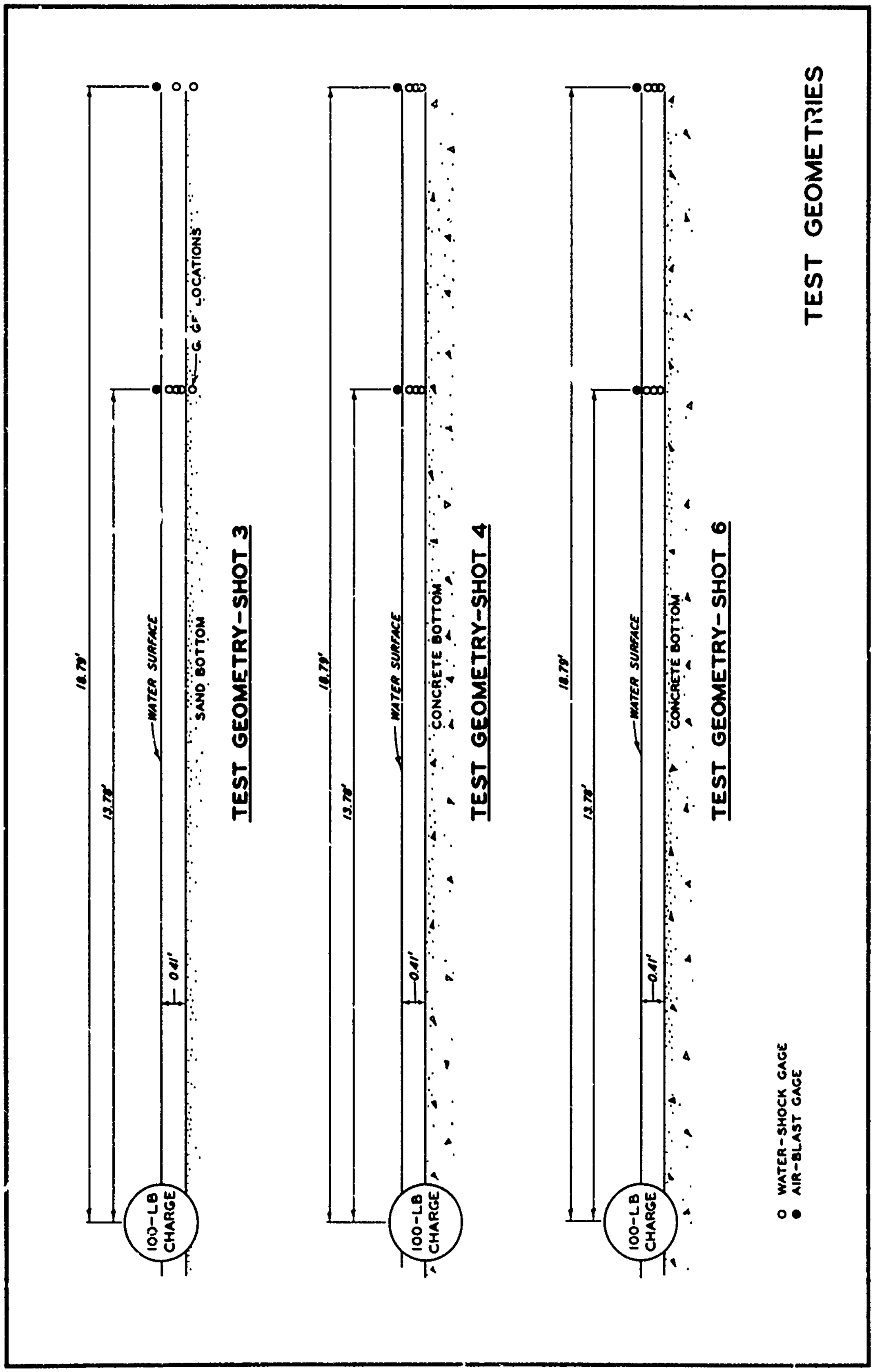
TEST GEOMETRIES
TEST GEOMETRY-SHOT 3
TEST GEOMETRY-SHOT 4
TEST GEOMETRY-SHOT 6
100-LB CHARGE
WATER SURFACE
SAND BOTTOM
CONCRETE BOTTOM
GAGE LOCATIONS
18.78'
13.78'
0.41'
○ WATER-SHOCK GAGE
● AIR-BLAST GAGE

PLATE 1

[redacted]

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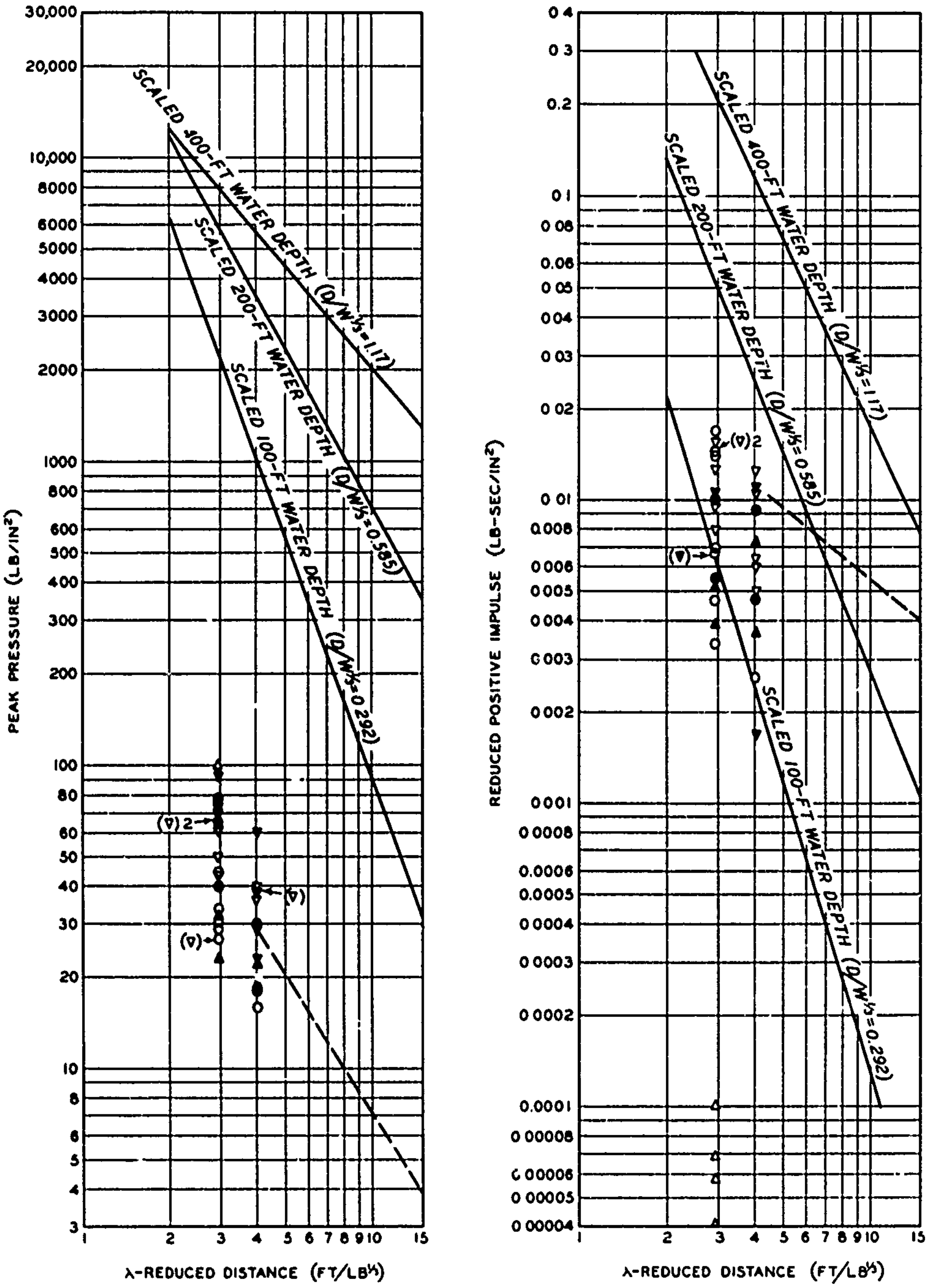

O SHOT 3
Δ SHOT 4
∇ SHOT 6
——— WATER SHOCK
– – – AIR BLAST

PLOTTED POINTS PRESENT NOL-56 DATA OPEN AND CLOSED SYMBOLS DENOTE READINGS FROM GAGES POSITIONED BELOW AND ABOVE WATER SURFACE, RESPECTIVELY

WATER-SHOCK CURVES WERE PLOTTED FROM DATA OBTAINED IN THE WES STUDY, "EFFECTS OF EXPLOSIONS ON GRAVITY DAMS," WHERE THE CHARGE AND GAGES WERE PLACED AT MID-DEPTH

AIR-BLAST CURVES ARE FOR CHARGES POSITIONED AT THE WATER SURFACE (DATA TAKEN FROM THE WES STUDY, "EFFECTS OF EXPLOSIONS IN SHALLOW WATER," REPORTS 5 AND 6)

VARIATION OF PEAK PRESSURE AND REDUCED POSITIVE IMPULSE WITH REDUCED DISTANCE

PLATE 2

[redacted]